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INFLUENCE OF THICKNESS OF COATED LAYER ON PARAMETERS AND KINETICS OF MECHANICAL ACTIVATION (EXAMPLE OF QUARTZ PROCESSING)

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Abstract

This paper describes, theoretical and application aspects concerning material treatment in dinamic type mills. A model is presented that describes the influence of tickness of coated layer of ground material on the disintegrator surface or milling bodies on parameters and kinetics of mechanical activation. Application of the model to quartz milling is presented in the paper.

Introduction

One of the well-known factors, which hold back wide introduction of mechanical activation methods is the absence of a visual quality monitoring of the behavior of materials inside mill reactors. So, the need for the development of the theoretical models which can adequately describe mill or disintegrator conditions and materials activation is very real today.

In the theoretical part of this paper, the authors show the modeling basis using the example of pressure impulse and temperature changes on shock contact of milling bodies and mechanically activated particles.

In real conditions the output of mechanochemical synthesis products is only a few percent. One of the reasons of such low output, taking into consideration also dissipation energy, may be formation of a ground material layer on the disintegrator surface or milling bodies. The quartz processing in the planet centrifugal mill is a good example of either distribution of pressure or the temperature impulse connected with it on the layer depth during the impact moment of milling body.

Model Formulation and Application to Quartz Processing

It is known [1,2] that processes in mechanochemical reactors (MR) in a number of cases do not flow to the end. For example, in the process of growing shallow (breakage) the fact of dynamic equilibrium takes place by the sizes of the mechanically activated (MA) particles [3-5], which is a part of enough studied concept of « mechanochemical equilibrium» [1,2,6,7]. The presence of dynamic equilibrium between the processes of destruction and aggregating of particles serves as basis for flowing of the phenomenon of self-fettling surface of the grindings bodies of MR (Fig. 1(a)) with the thickness of the steel-lined layer δ [8-10]. In principle, it is near to the phenomena of compaction and agglutination of powders [11], a difference consists only of mechanochemical realization of these processes in MR. So for MA particles of quartz in a roll planetary mill have [12,13]:

$$\delta = m_1 / \rho_1 (1 - p) (\Pi_v + \Pi_b) \approx 4m_1 / \pi\rho_1 (\Pi_v + 4\pi R^2 N) \qquad (1)$$

Here ρ_1= 2590 kg/m^3 – solidness (density) of quartz, $p \approx 1-\pi/4$ - sponginess of layer, Π_v & Π_b - areas of walls of drum of mill and surface of rolls, R and N - radius and number of rolls, accordingly.

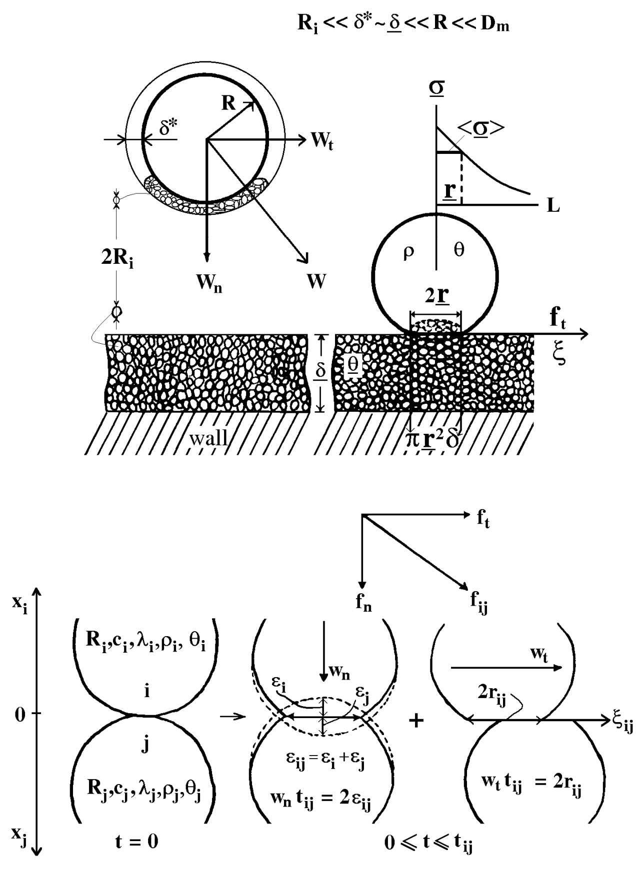

Figure 1. Chart of impact-frictional interactions of grindings bodies and MA of particles of quartz: a) grindings bodies; b) - any contacting particles i and j from the selected volume $\pi r^2 \delta$.

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On the other hand, in practice of study of processes of MA in MR, primary application belongs to the net balance of mass m_b of moving grindings bodies (roll loading for all types of roll mills) and by a hinge-plate m_1 of MA material [1,2,14,15]: $m_b / m_1 >> 1$. As a rule, this figure is about 50 (there is an about 2 g of the processed material on 100 g of the roll loading). Just the same choice of interaction m_b / m_1 is related to that at his considerable increase, the processes of MA in MR also flow not to the end or require unjustified long time of MA, caused by necessity of process of mass transition in MR, required to complete MA [16]. With an increase in m_b / m_1, the spending of mechanical energy become unjustified per unit of mass m_1 of MA material. As $m_b = 4\pi R^3\rho N / 3$, where ρ - solidness (density) of roll, then (1) is written down as:

$$\delta = m_1 / \rho_1 (1 - p) [\Pi_v + (3m_b / \rho R)] \approx 4m_1 / m_b \pi\rho_1 [(\Pi_v / m_b) + (3 / \rho R)] \sim m_1 / m_b \quad 1(a)$$

Expression 1(a) shows inversely proportional dependence of ratio δ; and m_b / m_1.

In [12,13] the process of MA of quartz was studied in steel roll 3 drums of the planetary mill, produced by NPO "Mekhanobr", in drums with capacity of 0.48 liter (0.00048 m^3). Affecting of the roll loading on particles of quartz is carried out through a layer δ; with relative speed **W** of co-impact of grindings bodies (Fig. 1(a)):

$$|\mathbf{W}| = 2\pi\omega D_1 [(\kappa + 1)^2 + \Gamma^2 - 2\Gamma(\kappa - 1) \cos\varphi + (\Gamma + 1)^2]^{0.5} = 16.7 \text{ м/с} \quad (2)$$

$$W_n = |\mathbf{W}| \sin\varphi = 15.8 \text{ м/с}, \ \& \quad W_t = |\mathbf{W}| \cos\varphi = 5.1 \text{ м/с} \quad (3)$$

Here D = 0.115 m and D_1 = 0.05 m - led and drums radiuses, $\omega = 11.7$ c^{-1} and $\omega_1 = 20$ c^{-1} – the frequencies of opposite rotation of led and drums, G = D/D1 = 2.3 - geometrical factor, $\kappa = \boldsymbol{\omega_1/\omega} = 1.7$ - kinematics factor, φ; - angle of roll breaking-away, $\cos\varphi = -(1+k) / G$, and W_n and W_t - normal and tangential constituents **W**. Relation m_b to mass of MA of quartz m_1 it was equal 4 at $m_b + m_1 = 0.48 + 0.12 = 0.6$ kg

The radius of rolls made R = 0.005 m, solidness (density) $\rho = 7800$ kg/m^3, number N = 120, total surface of $\Pi_b = 4\pi R^2 N \approx$; 0.037 m^2, cylindrical («working») constituent of area of surface of drum of $\Pi_v = 2\pi D_1 h \approx 017$ m2, where h = 0.055 m - height of drum. Calculation on (1a) gives $\delta \approx 10^{-3}$ m, that more than on the order of size more than for traditional values m_b / m_1 или $\delta = 10^{-4}$ -10^{-5}m, accepted at the calculations of kinetics of mechanochemical processes [10]. Theoretical description of MA of quartz is presented in [12,13]. Calculations were conducted for « equilibration» radius of particles of quartz $R_1 = 3\times10^{-7}$ m [3] except the influence of thickness δ fettling layer of the processed matters on parameters and kinetics of MA. Therefore, for the traditionally accepted periods of MA (to 90 minutes) the reaction of iron oxidization of abrasive wear of grindings bodies with subsequent formation of silicates of iron on-the-spot quartz particles flows incompletely - just on ~10% [12,13].

Thus, it is possible to state the possibility of substantial influence of value δ on parameters and kinetics of processes of MA of quartz at m_1 in relation to near to m_b. Below we made the first attempt to introduce the ratio δ for the theoretical estimation of parameters of MA matters on the example of treating the quartz according to above presented method.

It is known [17]from the of powders' pressing theory, that the key parameter - mechanical tension σ on the impact-friction contacts of grindings bodies and MA particles, must depend on the thickness of the pressed powder-like material:

$$\sigma(h) = \sigma_0 \, exp\,(-2\,\eta\,\xi\,h / r) \quad (4)$$

where $0 \le h \le \delta$ - variable h on the height of pressing δ, σ_0 - push of pressing, r - pressing radius, η - coefficient of lateral pressure, ξ - coefficient of external friction.

Impulse of tension of pressing σ_0 on the surface (h = 0) of roll impact with the flat layer (curvature L_1= 0) of MA particles of quartz on the wall of a drum is described by the expression [10]:

$$\sigma_0 = (8/3\pi)(10\pi)^{0.2} [\rho (\theta + \theta_1)^{-4} W_n^2]^{0.2} \quad (5)$$

The force of interaction of grindings bodies F and radius r of the contact surface are determined expressions:

$$f = (2/3)\,(10\pi)^{0.6} R^2 \rho^{0.6} (\theta + \theta_1)^{-0.4} W_n^{1.2} \quad (6)$$

$$r = (1/2)\,[(3/2)\,f\,(\theta + \theta_1)\,R]^{1/3} \quad (7)$$

The calculations presented below were performed with applying the program Mathcad (version 13.0/2005). Results in (4)-(7) at η = 1 (coefficient of spacer pressure for polycrystalline material [17] – is designed [10] such and is flat layer [8, 9]), ξ = 0.3 (coefficient of dynamic friction of iron on quartz [18]) as illustrated in Fig. 2.

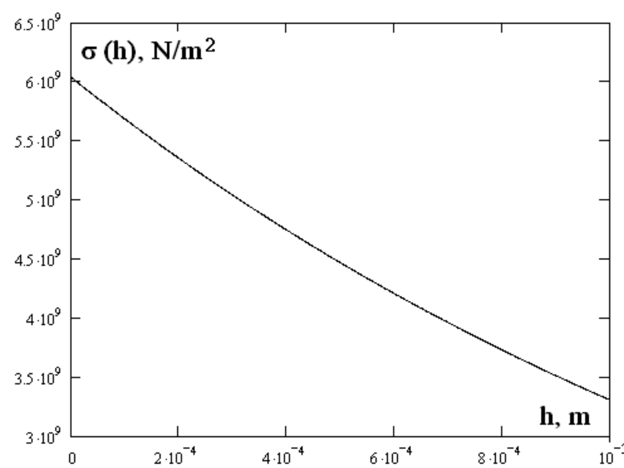

Figure 2. Changes of impulse of pressure σ in a depth h of flat layer of quartz particles

Temperature impulse $\Delta T(h,t)$ on the impact-friction contact of a roll with flat fettling layer of quartz particles (Fig. 1(a)) is described by the expression (8):

$$\Delta T(h,t) = \xi\,\sigma(h)\,W_t\,(cc_1\lambda\lambda_1\rho\rho_j)^{0.25}\{t^{0.5}\,iErfc[h/2(a_1t)^{0.5}] - (t-\tau)^{0.5}\,iErfc\,[h / 2a_1^{0.5}(t-\tau)^{0.5}]\} \quad (8)$$

Here $\tau = (\pi/4)\,[10\pi\,\rho\,(\theta + \theta_1)]^{0.4}\,R\,W_n^{-0.2}$ - the time of impact-friction interaction. In particular, on Fig. 3 they show a cut $\Delta T(h, t{=}\tau)$ – the change of maximal value of temperature on the depth of flat layer of quartz particles. It is evident, that the sharp falling of temperature takes place along the depth of layer (close to surface particles are warmed up only).

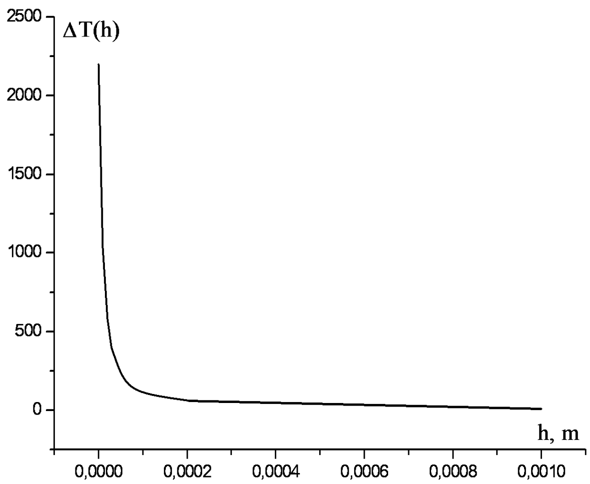

Figure 3. Temperature impact distribution ΔT on a thickness h layer of quartz particles distribution

Local warming-up $\Delta T(x, h, t)$ of quartz particles in the volume of fettling layer takes place on impact-frictional contacts as a result of impulse of pressure $\sigma(h)$ passing of on a fettling layer. In the calculations we do not taken into account distortion ***x*** of the contact flatness deep into the quartz' particles, see Fig. 1(b), i.e. it was accepted x = 0. To derive the formula for $\Delta T(h, t)$, it is necessary to revise the formulas developing for parameters of MA of particles in the volume of fettling layer [10,12,13] and bind them with $\sigma(h)$. Power f_1 of interaction of quartz particles now it will be determined by expression $f_1(h) = (f/s) = s_1(h)\,\sigma(h)$, where $s_1 = \pi r_1^2$ – is impact area of contacted particles, and $s = \pi r^2$, see (7). Then $s_1(h)$ is derived from expression $\mathbf{s_1(h)} = (\pi/4)\,[(3/2)\,\sigma(h)\,\mathbf{s_1(h)}\,\theta_1\,R_1]^{2/3}$::

$$s_1(h) = (\pi/4) \times [(3\pi/8)\,\sigma(h)\,\theta_1\,R_1]^2 = \pi \langle r_1(h)\rangle^2 \quad (9)$$

Knowing $s_1(h)$ we find $f_1(h) = [\sigma(h)\,\pi/4]^3 \times [(3/2)\,\theta_1\,R_1]^2$ and other parameters of MA of particles:

- total deformation (rapprochement) of contacting particles of quartz (Fig. 1(b))

$$2\varepsilon_1(h) = 2R_1\,[\sigma(h)\,\theta_1\,3\pi/8]^2 \quad (10)$$

- time τ_1 of particles' interaction is determined from expression $\tau_1(h) = 2\varepsilon_1(h) / w_n = 2r_1(h) / w_t$, where normal speed w_n we will find from

$$2\varepsilon_1(h) / \mathbf{w_n} = (\pi/4)(10\pi)^{0.4}\,[\mathbf{w_n^{-1}}\,2(\rho_1 R_1\theta_1)^2]^{0.2}$$

and is determined:

$$w_n = (2^{0.5}\,10\pi\,\rho_1\,R_1^{2.5}\,\theta_1)^{-0.5} \times [8\varepsilon_1(h) / \pi]^{1.25} = (9\pi)^{1.25}\,\theta_1^2 \langle\sigma(h)\rangle^{2.5} / 16(10\pi\,\rho_1)^{0.5} \quad (11)$$

- placing (9)-(11), we find $\tau_1(h)$ and tangent constituent $w_t(h)$ of particles (Fig. 4, 5)

$$\tau_1(h) = 2\varepsilon_1(h) / w_n = [5\pi^{2.5}\,\rho_1\,R_1^2 / 2^{0.5}\,3\sigma(h)]^{0.5} \quad (12)$$

$$w_t(h) = 2\,r_1(h) / \tau_1(h) = (3/8) \times [2^{0.5}\,3\langle\sigma(h)\rangle^3\,\theta_1^2 / 5\pi^{0.5}\,\rho_1]^{0.5} \quad (13)$$

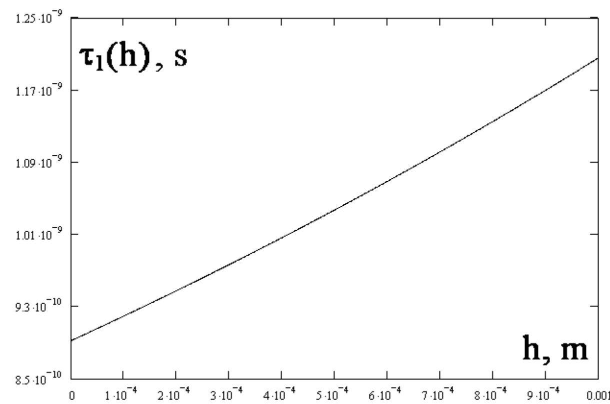

Figure 4. Time change of interaction of quartz particles along the depth of flat layer.

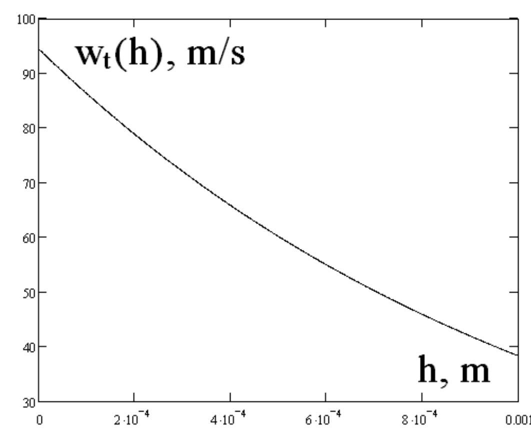

Figure 5. Changes of tangent speed of interaction of particles along the depth h..

Using (12) and (13) we define desired impulse of temperature on the surface of the particles:

$$\begin{aligned}\Delta T(h, t) &= 0.5642\ \xi_1\ \sigma(h)\ w_t(h)\ (c_1\lambda_1\rho_1)^{-0.5}\ \{t^{0.5} - [t-\tau_1(h)]^{0.5}\} \\ &= 0.5642\ \xi_1\ (3/8)\times[2^{0.5}\ 3 <\sigma(h)>^{5}\ \theta_1^{2} / 5\ \pi^{0.5}]^{0.5} \\ &\quad (c_1\lambda_1\rho_1^{2})^{-0.5}\ |\ t^{0.5} - \{t - [5\pi^{2.5}\ \rho_1\ R_1^{2} / 2^{0.5}\ 3\sigma(h)]^{0.5}\}^{0.5}\ |\end{aligned}$$

Here 0.5642 = *iErfc*, $\xi_1 = 0.65$ – is coefficient of dynamic friction between quartz particles [19,20]. Calculations are illustrated in Fig. 6, which state the most meaningful sections of impulse of temperature $\Delta T(h, t)$ on the friction contact of quartz particles:

- on the lower plane sections one finds along h and corresponding values τ_1 (Fig. 4);
- on a right lateral plane a section $\Delta T[h, \tau_1(h)]$ is given on a depth h of fettling layer; on the left plane a section $\Delta T[h(\tau_1), \tau_1]$ is given at time τ_1 of interaction of quartz particles.

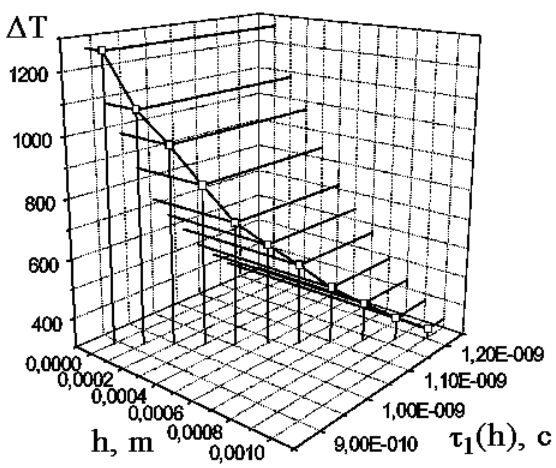

Figure 6. Changes of impulse of temperature $\Delta T(h, t)$ along the depth h and within time τ_1

Concluding Remarks

Thus, the performed calculations specify on substantial influence of thickness of fettling layer on the parameters of MA of the matters processed in a planetary mill and, as a result on kinetics of mechanochemical processes. We should mark, that in obedience to expressions (1) the thickness of fettling layer of the processed material is totally determined by the size of hinge-plates of load and by the area of surface of grindings bodies (walls of drum and roll loading).

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